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Impacts of increasing renewable energy subsidies and phasing out fossil fuel subsidies in China

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ABSTRACT

Subsidies to fossil-fuel consumption have made China's energy system fragile and unsustainable. It is necessary for China to reform fossil-fuel subsidies and reflect the resource cost and environmental cost in energy prices. Considering the life-cycle external costs, this paper estimates the scale of fossil-fuel subsidy and the true cost of renewable energy in 2010 and evaluates impacts of increasing renewable energy subsidies and phasing out fossil fuel subsidies on macro-economy and energy system in China based on scenario analysis. Simulation results show that the negative impacts on economic growth can be reduced from 4.460% to 0.432%, if only 10% of fossil fuel subsidies were removed. Increasing subsidies for renewable energy has positive impacts on macroeconomic variables. Although the economic benefits per unit of subsidies for renewable energy are lower than those for fossil fuels by 0.06–0.19 CNY, the revenue gap can be narrowed by shifting more subsidies from fossil fuels to renewables. Increasing subsidies for renewable energy helps optimize China's energy system in three ways: the first is making energy consumption structure cleaner; the second is improving energy efficiency; and the third is addressing the problem of imbalanced distribution and consumption of energy.

Contents

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1. Introduction

China's energy system has been environmentally unsustainable due to increased use of coal. More importantly, energy consumption in China has huge potential for growth: first, China's urbanization and industrialization process, which is projected not to come to an end until at least 2020, is characterized by rapid growth of energy consumption and rigid demand [1]; second, China's energy consumption per capita is still relatively low. The situation of future carbon emissions reduction would also be tough. Both of China's energy and electricity structures are dominated by coal, which are difficult to change in the short term. Coal is the cheapest type of energy, while has the highest carbon content. It can be estimated that China will continue to be the major driving force of the growth in global carbon emissions. In addition, with rapid and continual growth of energy consumption, the contradiction between energy supply and demand in China will get worse, and the rising energy price as well as foreign oil dependence will greatly threat national energy security.

However, the Chinese government keeps subsidizing fossil fuels by price regulation. One purpose is to support economic growth by lower energy cost. For instance, in order to reduce the cost of electricity generation, the Chinese government required coal enterprises to sale coal to electric-generation companies below the market price; and in order to enhance industrial competitiveness, the Chinese government regulated the ex-factory price of natural gas and provided preferential electricity tariffs to energy-intensive industries, etc. The other purpose is to alleviate energy poverty. For example, in order to enable access to modern sources of energy, the Chinese government fixed the residential electricity price and controlled prices of natural gas as well as oil products. However, the inefficient subsidy mechanism has led to the excessive subsidies for fossil fuels. On one hand, price distortions of fossil fuels have resulted in inefficient use of energy and wasteful consumption. On the other, low prices of fossil fuels have inhabited technological innovation and renewable energy development in China. In particular, China's energy subsidies benefit the rich far more than the poor due to poor targeting of subsidies [2].

On the G20 summit in Pittsburgh in September 2009, G20 committed "to rationalize and phase out over the medium term inefficient fossil fuel subsidies that encourage wasteful consumption". The pledge was repeated at the 19th Asia-Pacific Economic Cooperation (APEC) Economic Leaders Meeting in 2011 and the UN Conference on Sustainable Development in 2012. Increasing subsidies for renewable energy is an effective measure for coping with climate change, meeting energy access challenge [3], and promoting economic growth through job creation. Subsidies for renewable energy in China lagged far behind those for fossil fuels, which discouraged renewable energy production and investment. The International Energy Agency (IEA) [4] estimated that, apart from wind power, sources of renewable energy still need subsidies at least over the next two decades to remain competitive, particularly if fossil fuels continue to receive subsidies and their environmental impacts are not priced. Renewable energy subsidies are common in developed and developing countries, which are aimed at correcting market failures, increasing energy access, building up domestic industrial capacity to manufacture renewable energy equipment, and so on. The adjustment of energy subsidy from fossil fuels to renewable energy is beneficial for optimizing China's energy system [5]. From the perspective of demand side, only by rationalizing energy prices can energy conservation be achieved, and only by reflecting the environmental and resource costs of fossil fuels can renewable energy be price-competitive. From the perspective of supply side, increasing subsidies for renewable energy contributes to the increased supply of renewable energy, thereby helps ease the contradiction between energy supply and demand and energy price volatility.

Considering the life-cycle external costs of different types of energy, this paper estimates the scale of fossil-fuel subsidy and the true cost of renewable energy in 2010, and evaluates impacts of energy subsidy adjustment on China's economic growth and energy system. The remainder of this paper is organized as follows. Section 2 presents literature review. Section 3 determines subsidies in China's energy system. Section 4 evaluates impacts of energy subsidy adjustment from fossil fuels to renewable energy. Section 5 summarizes our findings and draws policy implications.

2. Literature review

Studies on energy subsidies are mainly focused on two aspects: the estimation of energy subsidy amounts, and the impact evaluation of energy subsidy removal [6]. According to the World Bank [7], the total order of magnitude of subsidies to consumers and producers is roughly equivalent to 1% of world GDP. Subsidy measures in demand side (consumers) are mainly price controls, transfer payments and consumer tax relief, etc., which are prevalent in developing countries. Global Subsidies Initiative (GSI) [8] indicated that, energy subsidies in demand side in the world's 20 largest non-OECD countries were US$ 400 billion in the year 2007. Subsidies in the supply side aim at increasing the income (e.g. lowering taxes, supporting research and development) or reducing the cost (such as increasing the supply price) of energy producers. Supply-side subsidies are more prevalent in developed countries, which have been gradually shifted from fossil fuels to renewable energy [9]. According to IEA [4], subsidies for renewable energy were about US$ 66 billion in 2010, of which renewable electricity accounted for 66.7%. EIA [10] indicated that energy subsidies in the U.S. amounted to US$ 37.2 billion in 2010, and subsidies to renewable energy accounted for 40%. Silveira et al. [11] highlighted the importance of financial subsidy from the government for implementation of photovoltaic solar energy. Chang et al. [12] explored the causal relationship of solar water heater (SWH) installation in Taiwan and showed that if the government continues to subsidize SWH installation with NT$2250/$m^2$, SWH installation areas will reach the promoted target of 140,000 m^2 by 2020.

Phasing out fossil fuel subsidies has social, economic and environmental impacts. OECD [13] showed that if the world's fossil-fuel subsidies on industry were eliminated, carbon emissions would decrease by 6.2% and the real income would increase by 0.1% in 2010 in comparison to the baseline scenario. According to IEA, OECD and the World Bank [14], the complete phase-out of

consumption-related fossil-fuel subsidies between 2011 and 2020 would cut global primary energy demand and carbon emissions by 5% and 5.8%, respectively by 2020, comparing with a baseline case in which subsidy rates remain unchanged. However, the impacts of fossil-fuel subsidy reform would be different for different countries. Taking Australia as an example, Riedy and Diesendorf [15] indicated that, the reform of inefficient fossil fuel subsidies in developed countries has the potential to provide substantial gains in economic efficiency as well as reductions in carbon dioxide emissions. ESMAP [16] showed that the removal of electricity subsidies in Mexico would reduce household welfare, especially for low-income households. Bazilian and Onyeji [17] indicated that, the elimination of fossil-fuel subsidies in developing countries which lacking of energy and resources, would lead to a decline in the competitiveness of enterprises and household income, and the slowdown of economic growth due to rising prices.

Studies on China's energy subsidies are mainly concentrated in two fields: the estimation of subsidy scale and the impacts of phasing out energy subsidy on social welfare. According to Lin and Jiang [18], fossil-fuel subsidy in China was about 356.43 billion CNY, accounting for 1.43% of the GDP in 2007. The study also pointed out that, as a developing country, it is somewhat reasonable for China to subsidize fossil fuels; however, considering energy efficiency and the structure of energy system, it is necessary for China to reduce fossil-fuel subsidies gradually, change the way of subsidy, and improve the effectiveness of energy subsidies. Yao et al. [19] examined the feasibility of eliminating China's fossil-fuel subsidies and encouraging subsidies for renewable energy. Results indicated that subsidy removal would have large negative impacts on macroeconomic variables. From the technical and economic perspectives, Liu and Li [20] analyzed the possibility and scope of improving China's energy consumption structure, and pointed out that energy consumption structure in China could be improved by eliminating coal or oil subsidies, but the economic and social indicators would be significantly affected. Li and Xie [21] indicated that fossil energy subsidies reform would have important impacts on different income groups; and proposed that China should phase out fossil energy subsidies gradually with taking the regional difference into account. Studies on renewable energy subsidy mainly focused on government policy. Ming et al. [22] introduced the current development situation of renewable energy, analyzed the evolution and implementation effect of the renewable energy tariff policy and discussed the problems of the renewable energy tariff policy in China. Xingang et al. [23] analyzed the subsidy policy and discussed the problems of the electricity price mechanisms and policies in China and proposed that government should formulate more policies to encourage private and foreign enterprises to invest renewable energy industries as well as to apply the CDM mechanism. Lo [5] reviewed China's renewable energy and energy efficiency (REEE) policies in six sectors: electricity, industry, transportation, buildings, and local government and identified limitations and room for improvement. Zhang et al. [24] sorted out China polices of biomass power generation policy, from 2006 to 2012, based on the actual demand of the biomass power generation project and analyzed the problems about the policies.

Existing studies are still limited in the following four aspects: first, estimates of fossil-fuel subsidies would be lower without including the resource and environmental cost of fossil fuels; second, the development potential for renewable energy could not be reflected without considering external costs of energy; third, impacts of reforming fossil-fuel subsidies on the overall energy system have not been discussed; fourth, mitigating measures to reduce the negative impact of fossil-fuel reform were not exactly proposed. Therefore, this paper attempts to contribute to the literature by addressing the above-mentioned questions.

3. Subsidies in China's energy system

3.1. Methodology

3.1.1. Estimates of energy subsidy

The "price-gap" approach has been widely used to estimate the scale of energy subsidies in developing countries [25]. In order to compare the true costs of fossil fuels and renewable energies, this paper includes the life-cycle external costs of fossil fuels in the reference prices. Reference prices are market prices that prevail in the absence of subsidies, which reflect the trade price in a competitive international market or the long-run marginal cost (LRMC) of production.

We assume that a country's energy demand is met by domestic productions and imports. Therefore, the reference prices need to be calculated.

$$RP_d = FOB + VAT + DC + LCEC \tag{1}$$

$$RP_i = CIP + IT + VAT + DC + ECC \tag{2}$$

where RP_d stands for the reference price of domestically produced fossil fuels, RP_i stands for the reference price of imported fossil fuels; VAT stands for value add taxes, IT stands for import tariffs, DC stands for distributional costs, $LCEC$ stands for life-cycle external costs of fossil fuels, ECC stands for the external costs of fossil-fuel consumption. Particularly, for oil products, we also include consumption tax in the calculation of reference price.

Energy subsidies can be estimated by the "price-gap" approach:

$$\text{Price gap} = \text{Reference price} - \text{consumer price} \tag{3}$$

$$\text{Energy subsidies} = \text{price gap} \times \text{energy consumption} \tag{4}$$

3.1.2. Impacts of energy subsidy removal

Impacts of eliminating energy subsidies depend on the form of demand function. In this paper, we adopt constant-elasticity inverse demand function described in IEA [25].

$$q = p^{\varepsilon} \tag{5}$$

The impact on consumption can be described by $\Delta q = Q_0 - Q_1$, in which

$$\ln Q_1 = \varepsilon \times (\ln P_1 - \ln P_0) + \ln Q_0 \tag{6}$$

where Δq is the decreased energy consumption when price gap has been removed; ε is the long-run price elasticity of energy demand; P_0 and Q_0 are the energy price and demand before the removal of the price gap, respectively; P_1 and Q_1 are the energy price and demand after the removal of the price gap, respectively.

Impacts of energy subsidy on CO_2 emissions can be described as

$$\Delta CO_2 = \sum_i \Delta q_i \times CO_2\, EF_i \tag{7}$$

where ΔCO_2 stands for the reduction of carbon dioxide emissions; i stands for the i-th fuel; $CO_2 EF_i$ stands for the CO_2 emission coefficient of the i-th fuel.

3.2. Reference prices of energies in China's energy system

3.2.1. Reference prices of fossil fuels

3.2.1.1. Coal. Electricity price of China has been administratively controlled by the government, which leads to the price control of thermal coal. In this paper, we use the average free on board (FOB) price of Qinhuangdao steam coal, 731.49 CNY/ton in 2010, as the reference price of domestically produced coal. Imported coal is assumed without subsidies, because the five largest power generation companies purchase it in the international market. In addition, we use the average freight rate from Qinhuangdao to

Table 1
Reference prices of China's fossil fuels in 2010.
Sources: [30–37]

Types of energy	Consumer price	Reference price of domestically produced fossil fuels	Reference price of imported fossil fuels	Life-cycle external cost
Coal (CNY/ton)	712.72	1006.18	[a]	195.22
Gasoline (CNY/ton)	8596.44	9120.87	9693.45	222.14
Diesel oil (CNY/ton)	7335.92	7957.36	8317.72	266.99
Fuel oil (CNY/ton)	4573.39	4755.19	5820.80	181.80
Kerosene (CNY/ton)	6069.67	8382.89	8612.44	443.98
Natural gas (CNY/m^3)				
Industry	2.88	5.52	5.51	0.005
Resident	2.47	5.56	5.53	0.022
Public service	2.68	5.53	5.52	0.011
Electricity (CNY/kWh)	0.51	1.13	–	–

[a] Imported coal were purchased directly from the international market by the five biggest power generation companies in China, so that we assume that this part of consumption is without subsidies, and the external cost of coal burning was CNY 97.1 per ton in 2010.

Shanghai, Guangzhou and Zhangjiagang as the distribution cost of coal, which was 79.47 CNY/ton in 2010. External costs of coal in China are from Greenpeace [26]. Environmental costs of coal mining, delivery and burning were 69.47, 34.05 and 91.7 CNY/ton (excluding the impacts of climate change). The distortion costs (the conflict between coal and electricity industries and resource depletion, etc.) due to government regulation amounted to 218.65 CNY/ton.

3.2.1.2. Oil products. In 2009, China introduced the new oil product pricing system. Domestic prices of oil products began to connect indirectly with those in the international market; however, prices of gasoline, diesel, and aviation kerosene were still regulated by the government. Due to the availability of data, we assume that the retail prices, determined by the National Development and Reform Commission (NDRC), are the same to all consumers. We choose the FOB prices from Platts as the reference prices of domestic oil products. Costs of retail and distribution were calculated at the 17 percent of the retail prices of oil products [27]. Over 60% of oil products in China are consumed in the field of transportation. Data of external costs of oil products are converted from NRC [28]. The life-cycle external costs of gasoline, diesel oil, fuel oil and kerosene were 222.14, 266.99, 181.80 and 443.98 CNY/ton, respectively. Besides, we assume that the external costs of the consumption of oil products accounted for half their life-cycle costs in order to simplify the calculation.

3.2.1.3. Natural gas. The cost-plus method under the state regulation is adopted as the pricing mechanism of natural gas in China. The upstream ex-factory prices adopt the pricing method of cost plus reasonable profits, the midstream pipeline transmission prices are guided by the central government, and the downstream distribution prices, which are related to income levels of certain consumer groups, are determined by the local governments. It is impossible to obtain the actual production cost of natural gas under price regulation, and the true cost of natural gas in China cannot be reflected by the low price of natural gas in North America. Therefore, we use the price of liquefied petroleum gas as the reference price of natural gas. External costs of natural gas are converted from NRC [28]. The external costs of the consumption of natural gas in China were 0.022 CNY/m^3 in the residential sector, 0.011 CNY/m^3 in the commercial sector and 0.005 CNY/m^3 in the industrial sector.

3.2.1.4. Electricity. The pricing of electricity in China is confusing, which has been administratively determined by historical levels and additional costs (such as costs of fuel, construction, operation and maintenance, and the regulated average profits). Based on estimates by Li et al. [29] and the adjustment of Consumer Price Index (CPI), the long-run marginal cost of residential electricity in China is CNY 1131.92 per MWh. External costs of power generation determined by factors such as fuel types, combustion equipment, technology and efficiency. China's power structure is coal-dominated (80%). Therefore, the external costs of power generation are mainly owing to coal burning, which have already been calculated in this article. On the other hand, external costs related to power transmission are still inconclusive. Since electricity is the secondary energy, it can be seen that there are no external costs of consumption.

Reference prices of China's fossil fuels in 2010 are shown in Table 1.

3.2.2. *Reference prices of renewable energies*

On-grid power tariffs of China's renewable energy are also determined by the government. In this paper, we use the levelized cost of electricity (LCOE) as the reference price of renewable energy [38]. LCOE is a handy tool for comparing the unit costs of different technologies over their economic life, which reflects the long-term costs of generating electricity by different power plants. The levelized costs of electricity generation of onshore wind and photovoltaics in China under the discount rates of 5% and 10% were estimated by OECD, IEA and NEA [39] without considering the costs of R&D investment, electricity transmission and interconnection. Power generation costs of biomass power plants (1–20 MW) are 5–12 cents/kWh [40], which are relatively constant in the short-term.

Increasing power generation of renewable energy will result in the increase of transmission investment. In which, the transmission cost of wind power was chose from LBNL [41], the transmission cost of photovoltaics was chose from Kannana [42], and the transmission costs of nuclear power, biomass and hydropower were chose from EIA [43]. If we take the impacts of intermittent characteristics of renewable power generation on electricity dispatch into account, the investment cost of renewable energy would be even higher. In this paper, we also include the external costs in the reference prices of renewable power generation [44,45]. Reference prices of China's renewable energy in 2010 are shown in Table 2.

It can be seen that the on-grid electricity prices of China's renewable energy were just above the minimum value of the LCOE of renewable energy at a discount rate of 5% (Table 2). Taking the investment needs in pre-R&D and fixed-asset, and the risk of

Table 2
Reference prices of renewable energy in China in 2010.

	LCOE (CNY/kWh)		External cost	Transmission cost	Reference price (CNY/kWh)		On-grid price
	At 5% discount rate	At 10% discount rate	(CNY/kWh)	(CNY/kWh)	At 5% discount rate	At 10% discount rate	(CNY/kWh)
Onshore wind	0.3545–0.6186	0.5004–0.8757	0.0089–0.0178	0.1043–0.1946	0.4676–0.8310	0.6136–1.0881	0.56
Solar PV	0.8549–1.2927	1.2997–1.9669	0.0534–0.1335	0.1390–0.2363	1.0473–1.6625	1.4921–2.3367	1.09
Biomass	0.3475	0.834	0.1068–0.1424	0.0695–0.1946	0.5238–0.6845	1.0103–1.1710	0.75

Table 3
Estimates of fossil-fuel subsidies in China and impacts of subsidy removal in 2010.

Energy types	Subsidy (billion CNY)	Share of subsidy in total (%)	Energy conservation due to subsidy removal	Potential Energy conservation (Mtce)	Carbon dioxide emissions reduction due to subsidy removal (Mt)
Coal	443.17	35.61	251.95, Mt	179.97	469.73
Gasoline	36.11	2.90	1.09, Mt	1.60	3.44
Diesel oil	91.63	7.36	3.19, Mt	4.65	9.99
Fuel oil	35.55	2.86	1.80, Mt	2.58	5.54
Kerosene	38.57	3.10	1.38, Mt	2.02	4.35
Natural gas					
Industry	181.40	14.58	21.72, bm^3	26.38	41.68
Resident	70.03	5.63	5.04, bm^3	6.12	9.67
Public service	30.41	2.44	2.15, bm^3	2.61	4.12
Electricity	317.64	25.52	60.36, TWh	7.42	37.47
Total	1244.50	100	–	233.35	586.00

Note: The average coal consumption of power generation in China was 333 g/kWh in 2010. In order to simplify the calculation, we assumed that the increased electricity consumption was fulfilled by coal-fired power plants.

investment into account, renewable energy development in China still needs more support from the government.

3.3. *Estimates of subsidies in China's energy system*

3.3.1. *The scale of fossil-fuel subsidies and impacts of subsidy removal*

Based on Eqs. (5) and (6), the reduced fossil-fuel consumption can be calculated with price elasticities of energy demand, and carbon dioxide emissions reduction can be calculated by Eq. (7). According to Lin and Jiang [18], the long-term price elasticity of thermal coal in China was estimated at -0.529, the long-term price elasticity of oil products in the field of transportation was estimated at -0.269, the long-term industrial and residential price elasticities of natural gas were estimated at -0.584 and -0.310, respectively, and the long-term price elasticity of residential electricity demand was -0.158. Estimates of fossil-fuel subsidies in China and impacts of subsidy removal in 2010 are shown in Table 3.

Taking external costs into account, the scale of fossil-fuel subsidies in 2010 was about 1.24 trillion CNY, which accounted for 3.10% of GDP in 2010 (See Table 3). From the perspectives of different fuel sources, coal subsidies amounted to 443.17 billion CNY, which accounted for 35.6% of total energy subsidies in 2010 and 1.1% of the GDP, and were responsible for the majority of energy subsidies. Reasons are as follows: first, nearly half of the coal consumption of power generation companies was fulfilled by contract coal. Government controls on coal prices and transportation capacity resulted to great deviations of the terminal consumer prices from the market prices. Second, China's coal consumption was mostly self-sufficient (97%), and the external costs of coal were the highest among fossil fuels. It is worth noting that owing to the oil price reform in 2009, the share of oil product subsidies in total energy subsidies was 16.3%, lower than the proportions of electricity (25.2%) and natural gas (22.6%).

If fossil-fuel subsidies were removed, the energy conservation potential would be 233.35 million tonnes of coal equivalent (Mtce), accounting for 7.58% of the primary energy consumption in 2010. The result indicates that energy subsidy reform helps improve the efficiency in energy utilization, thereby contributes to reduce energy consumption and carbon emissions in China [46].

Table 4
Required subsidies for renewable energy in China in 2010.

	Required subsidies at 5% discount rate (billion CNY)		Required subsidies at 10% discount rate (billion CNY)		Electricity production in 2010
	The upper limit	The lower limit	The upper limit	The lower limit	(million kWh)
Onshore wind	0	13.38	2.65	26.09	49,400
Solar PV	0	0.157	0.11	0.33	265
Biomass	0	0	1.93	3.13	7425
Total	0	13.54	4.69	29.55	57,090

3.3.2. *Required subsidies for renewable energy*

Renewable energy in China is mainly subsidized through renewable energy feed-in tariffs. In 2010, renewable energy subsidies amounted to 10.97 billion CNY, most of which were for electricity generation (97%). The true cost of renewable electricity is made up of production cost, the cost of investment in the power grid, and external cost. Additionally, discount rates and fuel prices are important assumptions of the LCOE for renewable power generation. Therefore, the true cost of renewable electricity would be different under different discount rates. To some extent, it reflects the cost uncertainty and investment risk of renewable energy. In order to fully compensate for the costs of renewable power generation, we calculate the required subsidies for renewable energy, and results are shown in Table 4.

There are various kinds of renewable energy subsidies, such as financial transfers, preferential tax treatment, regulations that create incentives to invest in renewable energy, support of physical infrastructure or access to natural resources, etc. Renewable energy subsidies have been common in developed countries,

including the U.S., Japan, the United Kingdom, Italy, and Spain. Energy subsidies can be beneficial, where they are aimed at promoting cleaner and more efficient technologies and at improving poor households' access to modern forms of energy [47].

Renewable energy development in China requires more subsidies. To compensate for the true cost of renewable power generation, the additional required subsidies would be 20.71 billion CNY (the lower limit) under the discount rate of 5%, and 5.75–150.62 billion CNY under the discount rate of 10%. The current subsidies are far from being able to make up the true cost of renewable power generation, and have little incentives to attract renewable energy investment. Therefore, in order to increase the proportion of renewable energy in total power generation in China, government needs to further increase subsidies for renewable energy.

4. Impacts of energy subsidy adjustment

4.1. Impacts on the macro-economy

4.1.1. Analytical framework

Computable general equilibrium (CGE) models have been commonly used in analyzing the consequences of macroeconomic policies and the impacts of resource allocation since the early 1980s. CGE models are preferred over the partial equilibrium model because they could include complex interdependencies in the analysis [48].

With two input factors of Labor and Capital, the impacts of endogenous government spending or taxes on the economy can be expressed as follows:

$$X_s = f_p(L, K) \tag{8}$$

$$w = \frac{\partial X_s}{\partial L} \tag{9}$$

$$X_s = \pi + wL \tag{10}$$

$$S = s_p(1-t)\pi + s_w(1-t)wL \tag{11}$$

$$I = I^* \tag{12}$$

$$S = I \tag{13}$$

In which, X_s, I, S, w, π, and t are endogenous variables. X_s is the neoclassical homogeneous production function; L and K are inputs, and w is the marginal productivity of Labor; π is the total income of Capital; s_w and s_p are the saving rates of income and output, respectively.

In this paper, we introduce energy and environment into the CGE model. In which, energy sector, composed by coal, oil, natural gas, and electricity, is one of the inputs in constant elasticity of substitution (CES) function. The analytical framework of the CGE model is shown in Fig. 1.

4.1.2. Macroeconomic impacts of energy subsidy adjustment

From the analysis above, China's fossil-fuel subsidies (including external costs) amounted to 1.24 trillion CNY, accounting for 3.1% of the GDP in 2010. Based on the considerations of economic development and poverty reduction, subsidies are sometimes reasonable or necessary for developing countries, especially for China [18]. If energy subsidies are inevitable, is it more reasonable and effective to shift subsidies from fossil fuels to renewable energy? By applying the CGE model, this paper tries to provide answers to the above question. We estimate the impacts of eliminating fossil-fuel subsidies and increasing the additional subsidies for renewable energy on macroeconomy and CO_2 emissions under different scenarios (see Table 5). We analyze the removal of fossil-fuel subsides based on three scenarios: Scenario 1 stands for the elimination of subsidies in 2010, Scenarios 2 and 3 represent removing fossil-fuel subsidies at the rates of 20% and 10%, respectively.

As shown in Table 5, if fossil fuel subsidies were eliminated (Scenario 1), the negative impacts on GDP (−4.460%) and employment (−4.027%) would be too high. Such an aggressive reform would barely be implemented, even if it helps significantly reduce energy intensities and CO_2 emissions. However, the negative impacts on GDP and employment could be lowered to −0.886% and −0.795% respectively, if fossil fuel subsidies were removed at

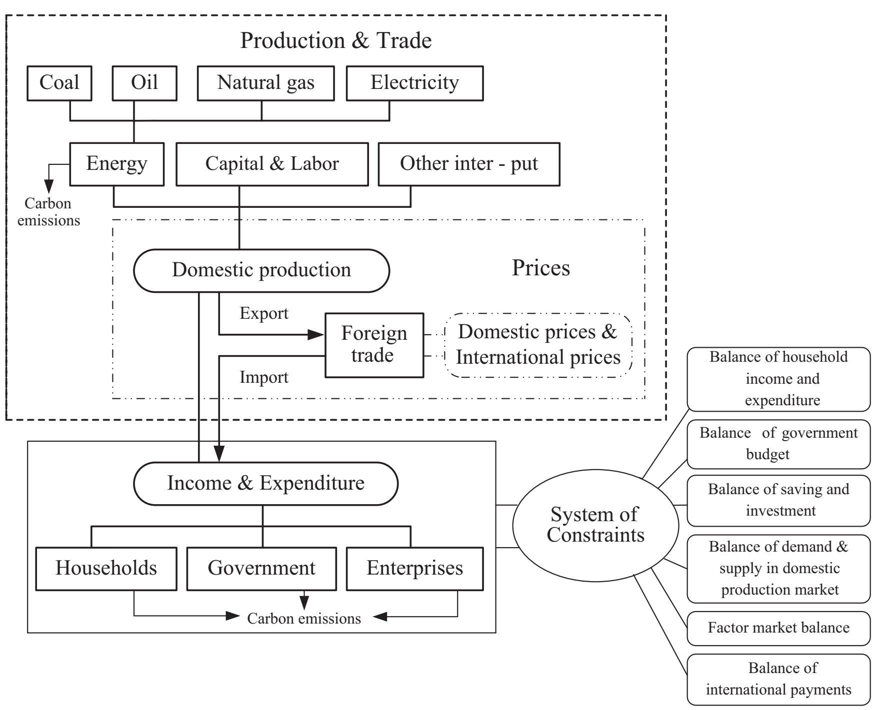

Fig. 1. Analytical framework of the CGE model.

Table 5
Impacts of fossil-fuel subsidy removal on macro-economy and carbon dioxide emissions.

Scenarios	Savings of fiscal expenditures (billion CNY)	GDP (%)	Employment (%)	Energy intensity (%)	CO_2 emissions (%)
Scenario 1	12444.96	−4.460	−4.027	−6.160	−7.420
Scenario 2	2488.99	−0.886	−0.795	−1.217	−1.445
Scenario 3	1244.5	−0.432	−0.393	−0.602	−0.713

Table 6
Impacts of increasing renewable energy subsidy on macro-economy and carbon dioxide emissions.

Increased amount of subsidy (billion CNY)	GDP (%)	Employment (%)	Energy consumption per unit of GDP (%)	CO_2 emissions (%)
4.69	0.009	0.006	−0.018	−0.014
13.54	0.029	0.021	−0.075	−0.051
29.55	0.057	0.040	−0.121	−0.094

the rate of 20% (Scenario 2). The negative impacts on GDP and employment could be further lowered to −0.432% and −0.393% respectively, if subsidies to fossil fuel consumption were removed at the rate of 10% (Scenario 3).

Results indicate that it will be operable for the Chinese government to gradually promote energy price reform. Currently, China is at an important development stage – moving from a low-income country to middle-income country, and the economic growth is a key factor ensuring social stability and development. Therefore, fossil-fuel price reform should be supplemented by mitigation measures. Increasing subsidies for renewable energy would be a workable policy. Impacts of increasing renewable energy subsidies are shown in Table 6.

As shown in Table 6, if subsidies for renewable energy were increased, GDP would be increased by 0.009–0.057% employment would be increased by 0.006–0.040% in 2010. Moreover, energy intensity could be reduced by 0.018–0.121% and CO_2 emissions related to energy consumption could be reduced by 0.014–0.094% [49].

It should be noted that, in our simulation model, subsidies shifted from fossil fuels to renewable energy were quite small, which only accounted for 0.038–0.237% of fossil-fuel subsidies (including life-cycle external costs) and 0.001–0.007% of GDP in 2010. Study of Kammen et al. [50] indicated that renewable energy helps promote economic growth and development needs in poor nations, as well as build energy independence and security in both industrialized and developing nations.

4.1.3. Comparison of the economic benefits per unit of subsidy

We conduct cost-benefit analysis (CBA) to compare the economic benefits per unit of subsidies for fossil fuels and renewable energy under different scenarios. If subsidies for fossil fuels in the year 2010 were eliminated, the GDP loss would be 1790.73 billion CNY. If subsidies for fossil fuels were removed at the rates of 20% and 10%, the GDP losses in 2010 would be 355.74 and 173.45 billion CNY, respectively. The GDP gain due to the increase in renewable energy subsidies amounted to 3.61–22.89 billion CNY.

The economic value of CO_2 emissions reduction can be measured by the income from carbon trading. We use the carbon-trading price from European Energy Exchange (EEX) as the economic value of carbon emissions reduction in China.[1] In 2010, the average trading price of carbon was 14–15 Euro per ton. According to IEA [52], China's carbon emissions amounted to 7217.06 million tons.[2]

Conserved energy is calculated from energy intensities change. If subsidies for fossil fuels were eliminated, energy conservation could be 200.16 Mtce.[3] If subsidies for fossil fuels were removed at the rates of 20% and 10%, conserved energies would be 39.54 and 19.56 Mtce, respectively. If required subsidies for clean energy were satisfied, energy conservation could be 0.58–3.93 Mtce. Energy conservation of different types of energy is estimated based on the primary energy structure in 2010 in order to simplify the calculation. Gains from energy conservation are the amounts of energy conservation multiplied by the corresponding reference prices.

The cost of unemployment can be regarded as the economic value of employment. Unemployment compensation in China is nearly 75% of the standard of minimum wage. Due to limited data, unemployment cost in this paper is the unemployed population multiplied by China's average minimum wage.[4]

Economic benefits per unit of subsidies for fossil fuels and renewable energy are shown in Table 7.

Table 7 shows that economic benefits per unit of fossil-fuel subsidy would be 1.311–1.315 CNY under Scenario 1, 1.293–1.297 CNY under Scenario 2, and 1.269–1.273 CNY under Scenario 3. Returns per unit of fossil-fuel subsidy decrease with smaller amount of subsidies. If subsidies for renewable energy were satisfied, returns per unit of subsidy would be 1.126–1.128 CNY for the lowest required subsidies and 1.210–1.211 CNY for the highest required subsidies. Returns per unit of subsidy for renewable energy are lower than those for fossil fuels by 0.06–0.19 CNY. However, with the increased amount of subsidies, returns per unit of renewable energy subsidy could be increased significantly, and the gap between returns per unit of subsidy for renewables and fossil fuels would be narrowed.

4.2. Impacts on energy system

4.2.1. Impacts on energy structure

Energy structure could be influenced by energy conservation of fossil fuels and the increase in renewable energy. Total energy conservation due to increasing subsidies for renewable energy and phasing out subsidies for fossil fuels accounted for 7.20–7.30% of China's energy consumption in 2010.[5] Impacts of energy subsidy adjustment on energy structure are shown in Table 8.

Increasing subsidies for renewable energy and phasing out subsidies for fossil fuels help optimize China's energy structure (Table 8). Compared with the actual energy consumption structure in 2010, share of coal in energy structure could be reduced by 0.02%, and share renewable energy could be increased by 0.04%. We should point out that, due to the limitations of price-gap approach and data, simulation results in this paper are static – without considering possible dynamic effects such as substitutions among different types of energy, the increased supply of renewable energy due to increased

[1] The EU emissions trading system (EU ETS) is the largest carbon trading scheme operating in the world today, issuing about two-thirds of the total volume

(*footnote continued*)
of carbon credits (which in this system are called EU allowances, or EUAs) worldwide, and accounting for almost 80% of carbon credit markets in terms of the value of credits traded [51].

[2] We adopt the average exchange rate (1 Euro=8.9763 CNY) in 2010 in our estimation.

[3] China's primary energy consumption in 2010 was 3249.39 Mtce.

[4] In 2010, the employed population in China was 761.05 million [30]; and the average minimum wage in China was 785.51 CNY/month [53].

[5] According to Table 3, with the elimination of fossil-fuel subsidy, the amounts of conserved energy from coal, oil, natural gas and electricity would be 179.97, 10.85, 35.11 and 7.42 Mtce in 2010, respectively. According to Table 6, if the true costs of renewable power generation are compensated, energy conservation would be up to 0.58–3.93 Mtce in 2010. Since China's power structure is coal-dominated (80%), we assume that electricity conservation by renewable energy development was thermal electricity.

Table 7
Economic benefits of subsidies for fossil fuels and renewable energy.

	Fossil fuels			Renewable energy	
	Scenario 1	Scenario 2	Scenario 3	The lower limit	The upper limit
Changes of subsidy (billion CNY)	−1244.50	−248.90	−124.45	4.69	29.55
Impacts on GDP (billion CNY)	−1790.73	−355.74	−173.45	3.61	22.89
Gains from carbon trading (billion CNY)	67.30–72.10	13.11–14.04	6.47–6.93	0.13–0.14	0.85–0.91
Gains from energy conservation (billion CNY)	375.92	74.27	36.74	1.11	7.47
Impacts on employment (billion CNY)	−288.89	−54.45	−28.19	0.43	2.87
Economic benefits per unit of subsidy (CNY)	1.311–1.315	1.293–1.297	1.269–1.273	1.126–1.128	1.210–1.211

Table 8
Impacts of energy subsidy adjustment on energy structure in China.

Energy structure	Range	*Coal, %*	*Petroleum,%*	*Natural gas,%*	*Hydro power, Nuclear power, and Other power, %*
Actual energy structure in 2010		68.07	18.97	4.35	8.61
Changes of energy structure		68.05	18.98	4.35	8.62

Table 9
Impacts of energy subsidy adjustment on energy efficiency in China.

Energy efficiency	Energy consumption (Mtce)	Adjusted GDP (billion CNY)	Energy efficiency (10,000 CNY / tce)
Actual values in 2010	3249.39	40,151	1.2356
Scenario 1	3043.26–3046.61	39759.72–40028.52	1.3042–1.3144
Scenario 2	3209.26–3205.91	40077.68–40082.61	1.2488–1.2503
Scenario 3	3229.25–3225.90	40117.61–40147.33	1.2423–1.2445

subsidies, etc. If we take substitution effects into consideration, price competitiveness of renewable energy would make its share in energy structure much higher than the simulated results.

4.2.2. Impacts on energy efficiency

According to World Energy Council (WEC)'s definition, energy efficiency improvements refer to a reduction in the energy used for a given service (heating, lighting, etc.) or level of activity, including technical, behavioral and economic changes. The economic indicator measuring energy efficiency is GDP or value added per unit of energy consumption [54]. Impacts of energy subsidy adjustment on energy efficiency are shown in Table 9.

Results show that energy efficiency can be improved by increasing renewable subsidies and phasing out fossil-fuel subsidies. Comparing to the actual value in 2010, energy efficiency can be improved by 5.55–6.38% under Scenario 1, 1.07–1.18% under Scenario 2, and 0.54–0.72% under Scenario 3.

To summarize, increasing renewable energy subsidies and phasing out subsidies to fossil fuels are conducive to reducing China's energy intensity, minimizing the costs of resource allocation, and improving the overall efficiency of China's energy system, which is consistent with the future energy policy direction.[6]

4.2.3. Impacts on the imbalanced distribution and consumption of energy

The energy system in China is characterized by the uneven or imbalanced distribution and consumption of energy resources. Such an imbalance leads to the following basic framework of energy flow and transmission: large-scale transportation of coal and oil over long distances from the north to the south, and transmission of natural gas and electricity from the west to the east [55]. Except for exploration and utilization, energy efficiency in China also faces problems of transmission efficiency and waste of resources. The imbalanced distribution of resources also makes it difficult to secure a sustained and steady supply of energy.

Increasing subsidies to renewable energy help address the problem of imbalanced distribution and consumption of energy in China. Solar energy resources are abundant in the North, Northwest and Southwest China and the average annual sunshine of East China also amounted to 2200–3000 hours. Wind power resources are mainly distributed in Northwest, Northeast, North, and East China. In 2010, installed capacity of wind power in Northeast China accounted for the largest share of China's total (12.04%), followed by North China (5.56%), Northwest China (3.73%) and East China (1.13%). Moreover, China's off-shore wind power (mainly distributed in East China) has realized a rapid development in recent years and the cumulative installed capacity has increased from 1.5 MW in 2007 to 389.6 MW in 2012. Biomass resources in China are mainly distributed in Northeast China (Liaoning, Jilin, etc.), North China (Hebei), East China (Shandong, Jiangsu, Fujian, etc.), the Central China (Henan, Hubei, etc.) and Southwest China (Sichuan, Guizhou, etc.). Above-mentioned provinces are located in or near the economically developed regions in China, and the development of biomass power generation helps support the electricity demands in these regions [56].

5. Conclusions and policy implications

Considering the life-cycle external costs of different types of energy, this paper estimates the scale of fossil-fuel subsidy in 2010, and evaluates impacts of fossil-fuel subsidy removal on energy conservation, CO_2 emissions and economic growth. Results indicate that the scale of fossil-fuel subsidies (including external costs) was 1.24 trillion CNY in 2010, accounting for 3.10% of the GDP. If

[6] The 12th Five-Year Plan (FYP) on Energy Development in China proposed the "dual control" principle of setting targets for both energy intensity and total energy consumption. By the year 2015, energy intensity in China would decrease by 16% comparing to the year 2010. Energy structure would also be optimized: share of coal would be decreased to 65%, and share of non-fossil energy would be increased to 11.4%. The capacity of renewable power generation would be greatly increased: wind power and solar PV would be increased by 26.4% and 89.5%, respectively.

fossil-fuel subsidies were eliminated, energy intensities and CO_2 emissions would be significantly reduced. However, the macroeconomy would be greatly affected, the negative impacts on GDP (-4.460%) and employment (-4.027%) would be too high to be affordable. The negative impacts on GDP and employment could be lowered to -0.886% and -0.795% respectively, if fossil fuel subsidies were reduced at the rate of 20%, and -0.432% and -0.393% respectively, if fossil fuel subsidies were reduced at the rate of 10%. Results suggest that it is operable for the government to gradually promote energy price reform in China.

Increasing subsidies for renewable energy provides an opportunity for achieving social goals. First, it encourages investment in renewable energy as well as technology research and development (R&D), which is conducive for China to seize the high ground of a new round of global energy transformation, economic and technological competition. Second, it stimulates economic growth, in particular, promotes the development of new energy industry in China, as well as helps alleviate energy poverty by the increased energy supply. Third, it optimizes energy consumption structure, helps improve the efficiency of energy system, reduces the dependence on fossil fuels, enhances national energy security, and thereby promotes the low-carbon transition of China.

Due to problems of cost uncertainty, high R&D investment requirement and high-risk investments, renewable energy development needs more support from the government to achieve the long-term economic and social sustainable development in China [57]. Results indicate that the economic benefits per unit of renewable energy subsidy can be larger than that of fossil-fuel subsidy, if the economic values of energy conservation and CO_2 emissions reduction are included. With the increasing depletion of fossil fuels, the rising prices of energy and climate change, subsidies for renewable energy would become more economical. For policy makers in China, if the social goals can be achieved, it would be easier for them to promote reforms on fossil-fuel subsidy.

If the government increased subsidies for renewable energy, it is possible to achieve reductions in energy intensity and CO_2 emissions and have a positive effect on the macro-economy [58]. The positive effect on GDP would be significantly increased, if we increase subsidies for renewable energy. Moreover, increasing subsidies for renewable energy help improve the overall efficiency of China's energy system: first, share of coal in energy structure could be reduced by 0.02% and share of renewable energy could be increased by 0.04% in 2010; second, energy efficiency can be improved by 0.54–6.38% under different scenarios; third, the problem of imbalanced distribution and consumption of energy in China could be addressed. In addition, the economic benefits per unit of fossil-fuel subsidy range from 1.269 to 1.315 CNY under different scenarios in 2010, which decrease with the decline in subsidies Although the economic benefits per unit of subsidy for renewable energy are lower than those for fossil fuels by 0.06–0.19 CNY, the gap can be narrowed by the adjustment of subsidy from fossil fuels to renewables.

To summarize, the keys to promoting renewable energy development in China are the reasonable and effective pricing of renewable energy and subsidy mechanism. On one hand, the government needs to establish a stable and long-term policy framework for renewable energy, in order to build the confidence of investors and expand renewable energy supply. On the other hand, the government needs to subsidize renewable energy differentially, and ensure the basic rights of low-income residents to access to modern energy under the effective and targeted subsidy mechanism.

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